AN UPDATED NUCLEAR REACTION NETWORK FOR BBN.

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The key Standard-Physics inputs of the Big Bang Nucleosynthesis (BBN) are the light nuclei reaction rates. Both the network and the nuclear rates have been recently reanalyzed and updated, and cosmological and New-Physics constraints (taking into account the WMAP Cosmic Microwave Background anisotropies measurement) obtained with a new code are presented.

Early Universe is a (hot) plasma in a FLRW metric whose composition and properties depend on the cosmic temperature T and that cools during universe expansion. The main events of its evolution depend on the *freezing* of some interaction during the cosmic expansion. BBN takes place when nuclear reactions (keeping baryons in chemical equilibrium) freeze-out, thus producing a characteristic pattern in light nuclide abundances.

BBN plays a fundamental role in *Cosmology*, where it can be used to check the internal consistence of the Standard Cosmological Model (SCM); in *Astrophysics*, e.g. to study the Li depletion mechanism in halo PopII stars, PopIII chemical composition or the Galactic Chemical Evolution; or to get a hint of *New-Physics*, because BBN is sensitive to the existence of other relativistic degrees of freedom (parameterized in N_{eff}), to ν's asymmetries, etc.

In its *minimal formulation*, BBN is an overconstrained theory: all the relevant observables depend on the only unknown parameter $\eta \equiv n_b/n_\gamma$, where n_b and n_γ are respectively the baryon and the photon number densities. The other parameters are Standard-Physics inputs, and the greatest uncertainties in standard BBN predictions arise from nuclear reaction rates R_k.

These rates are obtained as thermal averages of the relevant cross-sections σ. From a theoretical point of view, it is very difficult to use a *first principle approach* (strong interactions, many body problems, etc.), so one makes recourse to nuclear *models*. Moreover, experimental difficulties are present due to the low counting rates, strong energy dependence and corrections for electron screening. To obtain low energy extrapolations, fit the data and/or the theoretical predictions, it is useful to introduce some meaningful parameterizations, as the so-called *astrophysical S factor*.

In a completely general approach, the error matrix (due to nuclear uncertainties) for the nuclide abundances is given by the quantities:

$$\sigma^2_{ij}(\theta,R) \equiv \frac{1}{4}\sum_k \left[X_i(\theta,R_k+\delta R_k^+) - X_i(\theta,R_k-\delta R_k^-)\right] \times [i \to j] \tag{1}$$

with $\delta R_k^{\pm}$ the (temperature dependent) upper and lower uncertainties on R_k, respectively; R represents the collection of the nuclear reaction rates and θ the collection of the other relevant cosmological parameters (i.e. $\eta, N_{eff}, \ldots$). This slightly differs from the approach in [1] which assumes the existence (in principle not necessary) of the linear functionals $\lambda_{ik} = \partial \log X_i(\theta)/\partial \log R_k$. To properly define these quantities, the symmetric, temperature independent, relative uncertainties $\delta R_k/R_k$ are needed.

The analysis performed in [2] (see also [3, 4]) is restricted to a reduced network including the reactions relevant for the abundances of the nuclides with $A \leq 7$.
More than 80 reactions were examined, and many of the main reaction rates have been updated. Particularly useful tools in this work were furnished by the NACRE compilation [5], the LUNA measurement [6], or some recent theoretical predictions (e.g. [7], for the key reaction $p + n \to \gamma + {}^2H$). Moreover, in the new code the nuclear partition functions were introduced to include the role of excited states for nuclides whose mass number $A \geq 6$ [2, 5], and new reactions were added (as the ${}^3He + {}^3H \leftrightarrow \gamma + {}^6Li$, see [2, 3, 4]). The negligible role of plasma screening effects and of new three-body reactions was also confirmed [2, 4].

In the recent paper [3], some applications of this new code were performed: we (mainly) checked the internal consistence of the SCM (sections 4 and 5) and evaluated the BBN constraints on some New-Physics scenarios (section 7): e.g., we showed that in the Degenerate-BBN scenario a fourth sterile neutrino, as for example required to interpret LSND evidence for $\overline{\nu}_\mu \leftrightarrow \overline{\nu}_e$ oscillation, is not yet ruled out.

References

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